Quarterly Progress Report

Division 3

Radio Physics

15 April 1963

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Lexington, Massachusetts

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INTRODUCTION

This report summarizes the research and development efforts of Division 3 for the period 1 January through 31 March 1963. A substantial portion of the Division's activities is devoted to the Re-entry Physics and PRESS Programs, reports for which appear in the Semiannual Technical Summary Report and the Quarterly Letter Report to ARPA.

J. V. Harrington
Head, Division 3

T. F. Rogers
Associate Head

15 April 1963

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REPORTS BY AUTHORS IN DIVISION 3

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PUBLISHED REPORTS

Technical Reports

TR No.				ASTIA and Hayden Nos.
282	Radar Astronomy Measurement Techniques	P. E. Green, Jr.	12 December 1962	ASTIA 400563
291 (S)	Re-entry Body Discrimination by Observation of the Properties of the Turbulent Wake (title Unclassified)	R. E. Slattery W. G. Clay M. A. Herlin	11 December 1962	ASTIA 333863
292	Orbital Scatter Channel Propagation Experiment	P. R. Drouilhet J. W. Craig P. L. Fleck W. B. Smith C. A. Wagner	21 December 1962	ASTIA 401311
294	Photo-Ionized Cloud as Source for Decrease in Backscatter Cross Section of Re-entering Body	E. L. Murphy	17 January 1963	ASTIA 401310
297 (S)	A Survey of Re-entry Experiments with Applications to Project PRESS (title Unclassified)	S. Edelberg C. N. Bressel E. R. Bressel M. A. Herlin K. R. Johnson R. V. Meyer G. F. Pippert	25 January 1963	ASTIA 335800
300	The Diamond Circuit	R. H. Baker R. E. McMahon R. G. Burgess	30 January 1963	ASTIA 400955

G-Reports

No.				
34G-9	Confidence Intervals and Sample Sizes in the Measurement of Signal and Noise Powers, Signal-to-Noise Ratios and Probability of Error	J. L. Holsinger	3 January 1963	ASTIA 295133 H-466

Published G-Reports (Continued)

No.				
35G-3 [C]	Contribution of Air Dielectric to the Radar Cross Section of Re-entry Wakes (title Unclassified)	M. A. Herlin	25 February 1963	ASTIA 335098
37G-1	A Theorem on Fourier Integrals and an Application to the Theory of Measurement in Quantum Mechanics	H. E. Moses	5 February 1963	ASTIA 296789 H-479
312G-8	Scattering from a Radially Varying Plasma Cylinder of Infinite Length	C. M. deRidder L. G. Peterson	4 December 1962	ASTIA 294647 H-464
312G-13	Programs for Calculating a Predicted Radar Trajectory	K. Kresa M. R. Tausner	8 August 1962	ASTIA 296540 H-478

Published Journal Articles*

JA No.			
1958	A Circuit for the Square Root of the Sum of the Squares	T. E. Stern† R. M. Lerner	Proc. IEEE 51, 593 (1963)
1959	The Computation of Electromagnetic Scattering from Concentric Spherical Structures	J. J. Mikulski E. L. Murphy	Trans. IEEE, PGAP AP-11, 169 (1963)
1961	The Effect of the Earth's Magnetic Field on Irregularities of Ionization in the E Layer	F. Villars‡ H. Feshbach‡	J. Geophys. Res. 68, 1303 (1963)
1988	A Lunar Theory Reasserted – A Rebuttal	J. V. Evans	J. Research Natl. Bur. Standards 67D, 1 (1963)
1994	The Scattering Behavior of the Moon at Wavelengths of 3.6, 68 and 784 Centimeters	J. V. Evans G. H. Pettengill	J. Geophys. Res. 68, 423 (1963)
2007A	Experimental Study of Charge Drag on Orbiting Dipoles	I. I. Shapiro I. Maron† L. G. Kraft, Jr.	J. Geophys. Res. 68, 1845 (1963)
2009	The Microwave Spectrum of Oxygen in the Earth's Atmosphere	M. L. Meeks A. E. Lilley†	J. Geophys. Res. 68, 1683 (1963)
2053	Radar Observations of Venus, 1961 and 1959	W. B. Smith	Astron. J. 68, 15 (1963)

* Reprints available.

† Author not at Lincoln Laboratory.

‡ Consultant.

UNPUBLISHED REPORTS

Journal Articles

JA No.			
1990	Exact Probability Distribution Functions of Test Length for Sequential Processors with Discrete Input Data	J. G. Proakis	Accepted by Trans. IEEE, PGIT
2026	Aberration Theories for Semi-Automatic Lens Design by Electronic Computers. Part I: Preliminary Remarks; Part II: A Specific Computer Program	D. S. Grey	Accepted by J. Opt. Soc. Am.
2064	The Orthomatch Data Transmission System	B. G. Kuhn* K. H. Morey* W. B. Smith	Accepted by Trans. IEEE, PGSET
2078	Interactions Between a Hypersonic Wake and a Following Hypersonic Projectile	R. E. Slattery W.G. Clay R.R. Stevens	Accepted by AIAA J.
2087	Geomagnetic Effects on the Frequency Spectrum of Incoherent Backscatter Observed at 425 Mc/s at Trinidad, T. W. I.	V. C. Pineo D. P. Hynek G. H. Millman†	Accepted by J. Geophys. Res.
2101	The Influence of Terrain Shielding on Radio Wave Propagation at 8000 Mcps	W. E. Morrow, Jr. D. Karp R. V. Locke, Jr. W. C. Provencher	Accepted by Proc. IEEE (Correspondence)
2119	Observations of Ionospheric Movements by Incoherent Scattering	V. C. Pineo D. P. Hynek G. H. Millman†	Accepted by J. Geophys. Res.
2124	Equivalence and Anti-equivalence of Irreducible Sets of Operators. I. Finite Dimensional Spaces	H. E. Moses J. S. Lomont† K. Yu†	Accepted by J. Math. Phys.

Meeting Speeches‡

MS No.			
559A	The Diamond Circuit	R. H. Baker	Solid State Circuits Conference, Philadelphia, 20-22 February 1963

* Division 2.

† Author not at Lincoln Laboratory.

‡ Titles of Meeting Speeches are listed for information only. No copies are available for distribution.

Unpublished Meeting Speeches (Continued)

MS No.			
758	Attitude Sensing During Extra-Atmospheric and Re-entry Flight	K. Kresa C. R. Bohne	Space Flight Testing Conference, Cocoa Beach, Florida, 18-20 March 1963
767	Signalling Through Randomly Varying Media	P. E. Green, Jr.	M. I. T. Industrial Liaison Seminar, Dallas, 30 January 1963
771	The El Campo Solar Radar Antenna	M. E. Devane A. R. Dion	IEEE, PGAP, Boston, 26 February 1963
782	Radar Measurements of the Solar Corona at 38 Mcps	W. G. Abel	IEEE, PGAP, Boston, 26 February 1963
776	Modulation Techniques for Orbiting Dipole Scatter Communication	W. E. Morrow, Jr.	IAS 31st Annual Meeting, New York, 21 January 1963
783	Diamond Circuitry	R. H. Baker	Solid State Circuits Conference, Philadelphia, 20-22 February 1963
785	Automated Differential Correction of Optical System Designs	D. S. Grey	Optical Society of America, Jacksonville, Florida, 25-27 March 1963
803	The Optimization Problem	D. S. Grey	Seminar, Westinghouse Research Laboratories, Pittsburgh, 21 January 1963; Science of Optics, Lexington, Massachusetts, 23 January 1963
813	Detection and Estimation for Randomly Time-Varying Channels	P. E. Green, Jr.	IEEE, PGIT, Philadelphia, 14 March 1963
824	Long-Range Communications by Means of Orbiting Dipole Belts	W. E. Morrow, Jr.	AFCRL Colloquium, Bedford, Massachusetts, 7 February 1963
826	A Rowlometer Method of Measuring Surface Tolerances	L. J. Ricardi H. J. Rowland*	IEEE, PGAP, Waltham, Massachusetts, 20 March 1963
832	General Topics on Radar	L. J Ricardi	Arthur D. Little, Inc., Cambridge, 12 March 1963
839	Radar Observation of the Solar Corona	J H Chisholm	Seminar, Department of Astronomy, Cornell University, 28 February 1963

* Author not at Lincoln Laboratory.

Unpublished Meeting Speeches (Continued)

MS No.			
842	Radar Measurements of the Lunar Surface	G. H. Pettengill	NASA Symposium on Properties of the Lunar Surface, Washington, D. C., 4 March 1963
842A	Radar Investigation of Lunar and Planetary Surfaces	G. H. Pettengill	Symposium, Goddard Space Flight Center, 12 April 1963
848	Coding for a Discrete Information Source with the Distortion Measure	T. J. Goblick, Jr.	Communications and Data Processing Seminar, M. I. T., 8 March 1963
849	My Impressions of the Recent United Nations Conference on the Application of Science and Technology for the Benefit of the Less Developed Areas	T. F. Rogers	Symposium, M. I. T., 5 March 1963
850	Recent Experimental Studies of the Earth's Ionosphere	J. V. Evans	COMPASS Seminar, M. I. T., 12 March 1963; Joint Meteorological and Physics Colloquium, Florida State University, 26 March 1963; Seminar, University of Florida, 27 March 1963
859	Some Uses for Signal Representation with Emphasis on Speech	R. M. Lerner	Conference, Princeton University, 21-22 March 1963

For convenience in ordering copies of Lincoln Laboratory reports cited in this document, each reference is followed by its ASTIA number. In addition, Unclassified (released) reports have also been assigned Hayden serials (designated H-), indicating that they are obtainable, at cost, as microfilm or photoprint copies from the Microreproduction Laboratory, Hayden Memorial Library, M. I. T., Cambridge 39, Massachusetts.

ORGANIZATION

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Thomas F. Rogers, *Associate Head*
Charles F. Kaye, *Assistant*

GROUP 33

James H. Chisholm, *Leader*
Jesse C. James, *Assistant Leader*

W. G. Abel
L. E. Bird
R. P. Ingalls
L. P. Rainville

GROUP 34

Paul E. Green, Jr., *Leader*
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P. L. Fleck, Jr.
R. E. Gay
T. J. Goblick, Jr.
M. J. Levin
J. Proakis
W. B. Smith
L. M. Tahmoush
C. A. Wagner

GROUP 35

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Martin Balser, *Assistant Leader*

H. D. Fridman
W. M. Kornegay
W. C. Worthington

GROUP 36

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Richard H. Baker, *Assistant Leader*
Robert M. Lerner, *Assistant Leader*
Burt E. Nichols, *Assistant Leader*

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C. L. Mack, Jr.
D. C. MacLellan
J. Max
R. E. McMahon
J. Petriceks
R. O. Plaisted
F. W. Sarles, Jr.

GROUP 314

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James S. Arthur, *Assistant Leader*
Victor C. Pineo, *Assistant Leader*

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S. Weinreb

GROUP 315

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A. R. Dion
J. A. Kostriza
B. F. LaPage
C. A. Lindberg
J. B. Rankin
A. Sotiropoulos

RADIO PROPAGATION
GROUP 33

I. SOLAR RADAR STUDIES

The detectability of solar echoes with the El Campo (Texas) radar system is lowest during the months of December and January because of higher cosmic background and lower antenna gain. However, a few discernible echoes were obtained during this period. Solar experiments were suspended during February 1963 in order to make radar observations of Mars. In March a total of fifteen solar experiments were made, but echoes were obtained on only four occasions. The negative results obtained during the other eleven experiments may have resulted from using a different experimental technique. This possibility is being investigated.

Doppler analyses of signals recorded on magnetic tape during solar radar experiments made last summer are continuing. The results show that the Doppler spectrum is 20 kcps or greater in breadth, and that the peak of the spectrum occurs at about 4 kcps.

II. MARS RADAR EXPERIMENTS

During late January and February 1963, a series of about 56 individual radar observations were made of the planet Mars. No single experiment showed a discernible echo; however, when the outputs of all the experiments were combined a marginal result was obtained. The magnetic tape recordings made during the experiments are being carefully analyzed.

III. EL CAMPO ANTENNA

The El Campo array of 1016 dipoles was completed two years ago. This antenna produced a beam 13° east-west and about 1° north-south. It was used for the last time on 1 April 1963 for a series of radar observations of the moon. Disassembly of the array was begun on 2 April so that the parts could be used to construct a similar array with a dipole spacing twice as great. Construction of the new array was begun on 25 March and the expected completion date is 1 June 1963. It is hoped that this new array will increase the system sensitivity for solar experiments by about 3 db, and for Venus experiments by about 5 db. Some of the difficulties with corrosion, line expansion and grass will be eliminated in the new antenna.

IV. SOLAR RADAR DATA PROCESSING EQUIPMENT

Work continued on the second generation solar radar data processing system. A new digital unit which controls transmitting, receiving and data processing operations was designed and constructed. This control unit includes a number of new features that should make operation of the radar system more flexible and reliable. Moreover, replacement units for the analog integrator circuits were designed that should provide an expanded and more reliable output data processing system. A digital voltmeter and scanner readout system that will mechanize the acquisition of data

from the analog outputs of the radar was purchased and assembled. With the installation of these components at El Campo, the original receiver-exciter and data processing equipment will be replaced with a system specifically tailored to the solar radar experiment.

V. LAUNCH PHASE STUDIES

The final report on the launch phase studies is completed and will soon be published. The nature of the field measurements and their results is classified.

COMMUNICATION TECHNIQUES
GROUP 34

I. RADAR ASTRONOMY

A. L-Band Venus Radar Experiment

The signal processing equipment described in previous quarterly progress reports has been modified to extend the range of sampling frequency and allowable interpulse periods. This modification increases the efficiency of the detection program during analysis of low-bandwidth signals (e.g., ionospheric echoes and Venus echoes with millisecond pulses).

An attempt to detect Venus with this equipment was made on 15 February 1963; analysis of the data is awaiting final "debugging" of the computer program.

B. Haystack Data Processing

A series of discussions is in progress with members of Group 51 to assess the capabilities of the FX-2 pre-processing computer for real-time processing of radar-astronomy signals. As a typical example, a hypothetical range-Doppler mapping experiment of one of the inner planets is being considered.

It appears that the FX-2 is capable of performing the required processing in real time; however, in order to achieve the finest precision likely to be required, some additional external registers are needed.

II. ELF NOISE OBSERVATIONS

In the months since the FISH BOWL series of high-altitude nuclear shots, ELF data taken at the time of several of the larger explosions have been analyzed. The Star Fish shot of 9 July and the King Fish shot of 1 November produced ELF waveform transients at the time of detonation similar to those obtained by many other observers. There was, however, an additional and marked effect that specifically involves the earth-ionosphere cavity. Moments after the detonation time of both Star Fish and King Fish, the peak-power frequency of the first mode fell sharply from around 8.0 to about 7.5 cps; it took from 3 to 4 hours to recover its normal value. Similar shifts also occurred in the frequencies of the higher modes. It is not readily apparent why a change in such a small fraction of the cavity wall area should produce such a large shift in overall characteristics. We note, however, that the amount of abrupt frequency shift produced by the detonations was no greater than the much slower diurnal fluctuations in peak frequency regularly observed.

III. COMMUNICATION AND DETECTION THEORY

A. Decision-Directed Channel Measurement

The study of decision-directed channel measurement has been completed. Several detection systems have been simulated and in all cases decision-directed channel measurement has yielded

smaller error rates than the non-decision-directed channel measurement. The complete results will be presented in a forthcoming G-Report.

B. Anti-Jam Modulation

A recent study presents a simple comparison of the anti-jam performance of a certain frequency-hopping (FH) scheme with that of NOMAC (noise modulation and correlation) for the purpose of assessing their relative merits as modulation schemes for a high-altitude active-satellite communication system. The computations involved in the comparison are reasonably simple because of the assumption of negligible thermal noise.

Further work along these lines has continued in an attempt to make a more realistic comparison of frequency-hopping and NOMAC systems – a comparison that will include the effects of thermal noise and flexible jammer strategies. No coding has been included in the analysis thus far. The expressions for probability of error in binary FH and NOMAC systems were derived for several jammer strategies, and these expressions have been programmed for the IBM 7090. Each jammer strategy has been optimalized for various system parameters, such as TW, E/N_o, J/S. This study will be extended to nonbinary systems.

IV. DATA PROCESSING TECHNIQUES

An investigation of three methods of designing linear computer programs that perform filtering operations on equally spaced data samples is being made. The results have applications to the spectral analysis of data, and one method in particular provides a very direct and economical way (in terms of the number of computer operations) of designing a digital filter with a transfer function approximating that of the desired analog filter.

V. BOMB-QUAKE DISCRIMINATION

During this quarterly period, the small intergroup effort on the seismic discrimination problem has proceeded in several directions. A number of Vela Uniform recordings of seismic events and microseismic noise received by arrayed seismometers were borrowed from the Air Force Technical Applications Center. After a lengthy period of checkout and debugging, processing of these data on the TX-2 computer is now proceeding. This processing is aimed toward establishing various discrimination criteria and toward defining a valid mathematical model of noise in arrays.

On the basis of recent work at Texas Instruments, Inc. and the University of California, it appears possible to set up a tentative model of the noise (to be verified as work proceeds) which allows definition of the statistical problem of optimally estimating the direction of arrival of a plane-wave signal incident on an array on which noise is also incident. The use of arrays for signal-to-noise maximization has been considered before, but the use of arrays for angle-of-arrival discrimination is not well understood. An attempt is being made to set this up as an analytical problem.

PLASMA PHYSICS
GROUP 35

I. LAUNCH PHASE SIMULATION

A. Gaseous-Discharge Experiments

Studies on the ionization breakdown of air and the subsequent neutralization of the plasma inside the cavity have been conducted as a preliminary to the complete exploding-sphere experiment. The electron density produced by the singly pulsed microwave discharge, its neutralization by the processes of recombination and attachment as a function of time, and the collision frequency for momentum transfer are being calculated for pressures from 0.06 to 5 torr of air inside the cavity. Gross experimental results indicate initial electron densities of the order of 10^8 electrons/cc and collision frequencies for air that are compatible with established values. Plans are being made to process the large amount of accumulated data on a digital computer. Langmuir probes have also been used in some of these studies. The effect of the transient plasma and the interaction between probes when several are used has created some difficulty of interpretation. A Langmuir probe with a guard ring attachment will henceforth be used in order to achieve a more uniform sheath across the face of the probe. At the same time, a DC discharge experiment has been set up for studying the steady-state behavior of the Langmuir probes and the characteristics of the associated circuitry.

B. Pressure Measurements in the Continuum and Transition Flow Regimes

The pressure probe calibration experiments in the Harvard College Observatory shock tube ($2\frac{1}{4}$ inches in diameter) have been completed. Measurements were made in helium and argon. The pressures to which the sensors were exposed ranged from 0.4 to 200 torr, and the free-stream Reynolds number, based on probe diameter, ranged between 36 and 10^4.

In the region of continuum flow (Reynolds number greater than 250), the experimental results are consistent with those obtained with the Avco-Everett Research Laboratory low-density shock tube.* In the transition flow regime (Reynolds number less than 250), the pressure measured by the probe is, as may be expected, higher than that predicted by the Rayleigh-Pitot formula when the probe sensitivity determined in the continuum regime is used. A set of corrections down to a Reynolds number of 36 has been experimentally derived. The pressure in the transition flow regime can now be calculated with reference to the pressure in the continuum flow regime.

Preliminary experiments with spherical shock waves indicate that these pressure corrections are valid. More spherical shock wave experiments will be carried out to ascertain whether the pressure correction can be extrapolated to lower Reynolds numbers.

* Division 3 Quarterly Progress Report (U), Lincoln Laboratory, M.I.T. (15 January 1963), ASTIA 296192.

COMMUNICATION SYSTEMS
GROUP 36

I. PROJECT WEST FORD

A. Camp Parks Site

A beam modulator has been added to the klystron transmitter for radar service permitting higher peak-pulse powers at reduced duty cycles; $87\frac{1}{2}$ kw at 8350 Mcps was achieved for an 800-msec pulse at a 20-cps repetition rate, a duty cycle of 1.6 percent. A helium-gas tube that is an externally pulsed attenuator is serving as the TR device to protect the receiver during transmission. The radar is once again operative.

B. Millstone Hill Site

The 25-kw transmitter at 7750 Mcps is now operating either CW or DC pulsed with a beam modulator. A pulsed-attenuator TR device has been added and the system now can operate as a radar. Either of two receiving systems, each with a maser, can be used: one at 8350 Mcps for receiving signals from Camp Parks, and one at 7700 Mcps for radar purposes.

C. Dipole Package

A redesigned West Ford package has been produced, tested and delivered to Vandenberg Air Force Base for launching. This package differs in several respects from the first West Ford packages. The dipole material consists of 0.0007-inch-diameter copper wire rather than 0.001-inch-diameter copper wire. The package is split into four 4-deck units and one 2-deck unit to which a telemetry package is attached (the original package consisted of a single unit of twenty-one decks). The method of ejection differs in that, although the subunits are ejected simultaneously, they separate from each other after they are free of the canister. However, the method of dispensing the dipoles remains essentially the same.

The dipole decks have been subjected to vibration and dispensing tests. The complete canister has been subjected to vibration tests, hot and cold ejection tests, vacuum leak tests, and centrifuge tests. All components functioned properly during these tests.

D. Telemetry

Three flight and two backup performance telemetry systems were constructed, tested and calibrated. Several minor circuit and fabrication changes were made to improve system performance. One of the flight telemetry systems was assembled into a complete West Ford payload and made available for a possible launch this spring.

II. MOON EXPERIMENTS

A. Camp Parks – England Teletype Test

On 5 April 1963, a cooperative experiment was undertaken with the Royal Aircraft Establishment at Farnborough, England. Teletype messages were transmitted from the West Ford

site in California to England via the moon. The receiving system at Farnborough included a 17-foot antenna and a crystal-mixer front end with an 8-db noise figure.

At the transmitter, two noise bands 200 kcps apart and each 60 kcps wide were keyed in a simple FSK manner at a 60-word-per-minute rate. The receiver demodulator consisted of two channels 200 kcps apart, each 60 kcps wide, acting as matched radiometers whose outputs fed a difference amplifier that determined whether "mark" or "space" was transmitted. Multipath from the moon produces a smear of about 500 μsec; therefore, tones 2 kcps apart will fade independently. Using a 60-kcps-wide noise band is thus equivalent to 30^{th} order frequency diversity.

Essentially error-free teletype copy was received with 10 kw transmitted from California.

B. Camp Parks – Transportable Station Teletype Test

A truck has been outfitted as a transportable receiving station with a tripod-mounted 18-inch or 4-foot antenna and equipped with a teletype demodulator similar to the one described above. A 5-kw motor-generator supplies primary power. When 1 kw was transmitted from Camp Parks, good TTY copy was received via the moon using the 4-foot antenna and a maser front end. With a crystal-mixer front end (noise figure of 8 db) and 20 kw transmitted, good copy was also received with the 4-foot antenna. With the 18-inch antenna and the maser, copy was also received when 20 kw was transmitted.

III. BEYOND-THE-HORIZON EXPERIMENTS

The truck described above has also been used to measure the effect of terrain shielding and beyond-the-horizon path loss at short distances. Measurements made in the summer of 1962 are reported in G-Report 36G-1.* Additional tests were made in March 1963 when snow was on the ground and the leaves were off the trees. Preliminary results indicate a loss in excess of free space to be about 91 db at one mile (about 10 db less than in the summer) and 130 db at eleven miles (about 15 db more than in the summer).

IV. ADVANCED AND THEORETICAL STUDIES

A. Delay-Line Filters

A common practical problem in signal processing is the need to have a specified frequency response over a fixed frequency range without regard for what that response becomes outside the range of interest. In addition, one may wish a transient response of finite duration in order to use a tapped delay line as a filter. These problems can be solved in principle by expanding the desired response in terms of prolate spheroidal wave functions; but for most of the interesting cases (signal TW product large) so little is known about these functions as to limit their use to existence proofs. Therefore, a rapidly converging computer program which finds practical solutions by a relaxation method has been developed. The results of this program have been used to improve the performance of the delay-line chirp filters described in the last quarterly progress report.†

* W. E. Morrow, et al., "The Influence of Terrain Shielding on Radio Wave Propagation at 8000 Mcps," 36G-1 [U], Lincoln Laboratory, M.I.T. (20 November 1962), ASTIA 290511, H-452.

† Division 3 Quarterly Progress Report [U], Lincoln Laboratory, M.I.T. (15 January 1963), p. 7, ASTIA 296192.

B. Linear-Phase Filter

It has been found practical to build linear-phase bandpass filters from crystals. The series resonances of the crystals are used in the design as simple L-C resonances; the shunt capacity is used in resonating the input and output transformers. An experimental filter with 23 poles in the band 100 to 104.6 kcps had ±0.15-db maximum (random) amplitude variation in the pass band, and phase errors less than the ±10° errors of the phasemeter.

V. ACTIVE SATELLITE SYSTEM

A. Repeater System

The microwave repeater system required in the proposed active satellite has been investigated from two points of view:

(1) System considerations, with the objective of improving and simplifying the RF system.

(2) Device evaluation.

Three specific changes have been proposed which offer the possibility o. system improvement:

(1) An RF antenna sensing and switching system utilizing the "FM capture effect."

(2) Simplification of the high-power transistorized source by generation of significant power at 500 Mcps.

(3) The possibility of combining a varactor frequency multiplier and an upper-sideband frequency converter into one device.

B. Components

Component evaluation has continued, especially evaluation of high-power and high-frequency transistors and varactors. The transistor experiments have shown that at 100 Mcps it is possible to generate significantly more than 100 watts (on a pulse basis) by the simple expedient of paralleling several 10-watt devices and over-driving the circuit.

Power at 200 Mcps has been obtained by frequency-doubling from a 100-Mcps source. Using high-capacitance, high-voltage devices, 80 watts of RF power has been observed at 200 Mcps on a pulsed basis.

Experimental transistors capable of operating at higher frequencies (200 Mcps to 1 kMcps) are now becoming available and will be evaluated more fully during the next report period. Initial circuits have resulted in a 500-Mcps, 2-watt power amplifier with a collector of 50 percent.

A varactor frequency multiplier chain, complete with a 70-Mcps transistorized driver, has been constructed. Two hundred milliwatts of output power has been obtained at 7.2 kMcps for a total DC power drain of 12 watts. Final doubler efficiency was 50 percent. During the next report period, the packaging of this chain will be completed.

C. Repeater Location

Several differential-velocity schemes for the placement of uncontrolled, nonrandom satellites have been worked out for specific (generally long and difficult) communication links. It has been found that zero-outage performance can be achieved with fewer than half as many satellites in orbit as would be required for 1 percent outage performance with randomly disposed satellites.

VI. TRANSISTOR CIRCUITS

A. Low-Noise Pulse Preamplifier

Large junction-area InSb diodes are being used as infrared detectors to measure radiation from semiconductor junctions. These diodes are operated in the photovoltaic mode; an approximate small-signal equivalent circuit consists of the parallel combination of a current source I (proportional to the input radiation), a resistor R ($R \approx KT/qI$), and the junction transition capacity. Since the InSb diode has a large junction area, the value of the transition capacity is also large – about 2000 picofarads. The infrared radiation occurs as pulses with a minimum pulse-width of 100 nanoseconds. Resistive loading of the InSb diode to obtain adequate response speed and the use of conventional amplifiers result in inadequate signal detectability at low signal levels.

A low-noise transistor preamplifier has been constructed for improved low signal-level operation. This amplifier uses two 2N918 transistors in a cascade circuit followed by a 2N918 emitter-follower, resulting in a voltage gain of 30 db. Coupling of the InSb diode to the input transistor is accomplished with a 1:8 ratio pulse transformer.

The transient response of the preamplifier to a current step function input to the transformer (with a 2000-pf capacitor in parallel with the transformer input) consists of a 20-nsec delay followed by a 40-nsec rise time and an exponential decay with a 3-μsec time constant. The preamplifier noise referred to the InSb diode current generator is approximately 0.25 μa peak-to-peak. Incorporation of the preamplifier into the infrared measurement system has resulted in a substantial reduction in the system noise.

B. Low-Power Transistor Circuits

Measurement of the parameters of the 2N2524 transistor at collector-current levels from 10^{-12} to 10^{-5} amp has been completed; measurements on the 2N2605 transistor (the p-n-p complement to the 2N2524) are in process and should be completed during the next quarterly period. These transistors permit the design of low-frequency and DC solid state operational amplifiers with extremely high-input dynamic resistances (up to 3×10^{11} ohms) and low-input leakage currents (less than 10^{-11} amp at room temperature).

Since circuits in a space-vehicle environment may encounter considerable temperature variation, a number of DC operational amplifier designs using these transistors have been investigated using a temperature environment requirement of $-40°$ to $100°C$. The configuration having the most stable operation with varying temperature is that of cascaded difference amplifiers. Such a configuration, properly designed, also allows maximum flexibility for stabilizing-feedback loops and operational-feedback loops. Two such amplifiers have been constructed but not yet tested.

In order to demonstrate the low power potentialities of such circuits, a standard multivibrator circuit has been built and tested, the transistors being operated at currents of less than a nanoampere. Cycle time, depending on the values of the cross-coupling capacitors, ranges from 40 sec to 18 hr. The power required by the multivibrator is 7.5×10^{-10} watt

C. Field-Effect Transistors

Under open-circuit input conditions, the equivalent input noise current of a field-effect transistor arises from two effects: (1) thermally generated noise in the channel and (2) shot noise

in the gate-leakage current. For most commercially available units, the shot noise seems to predominate. Various units are being measured to determine minimum gate-leakage operating points, and an effort is being made to design test circuits to measure the noise under open-circuit input conditions. The lowest input noise current reported thus far is about 10^{-14} amp/cps$^{1/2}$

D. Diamond Circuits

A voltage-level discriminator circuit has been built using modifications of the diamond circuit. At room temperature, the circuit has a threshold of 1 mv with no hysteresis and will operate from DC to 500kcps. By using high-frequency germanium transistors, it should be possible to extend the frequency of operation to several megacycles.

SURVEILLANCE TECHNIQUES
GROUP 314

I. MILLSTONE UPGRADING

The period ending 31 March 1963 found the tracking phase of the L-band conversion of the Millstone radar within several weeks of completion. The items delaying conversion at this time appear to be the 12-horn monopulse feed (Group 315) and the new ultrastable parametric receivers (Group 46). Both should be available for installation within the next several weeks.

The oil lubrication system for the 84-foot parabolic antenna mount has been completed and tested, final installation of all items in the equipment shelter completed, and the new 175-channel slip-ring assembly installed. Servo characteristics have been measured and the control loop tightened by about an order of magnitude (as compared to the previous performance at UHF).

The preparation of a manual describing in detail the construction and operation of every major piece of station equipment is well under way. Chapters describing the Sequential Doppler Processor, Doppler Analyzer Display, Station Crystal Clock, and Frequency-Synthesizer/Exciter are finished, with several others almost completed.

The early version of the X-780 L-band klystron developed by Eitel-McCullough, Inc. proved to have a very short operating lifetime. Of the five tubes put into operation at Millstone since 7 September 1962, four have failed after less than 100 hours of operation. Recently, an improved version has been produced in which, it is claimed, the previous shortcomings (vacuum seal leaks, arcing in the electron gun, and spurious modes in the output cavity) have been overcome. One of the new tubes is now being operated in the transmitter at Millstone, and it is hoped that it will prove as successful as the manufacturers claim.

Trouble with waveguide breakdown at relatively low peak power (less than 1 Mw) in the waveguide run between the azimuth-rotary joint and the feedhorn has been cured by increasing the tension on the waveguide flange bolts. Power levels in excess of 3 Mw may now be used without recourse to gases of high dielectric strength.

Initial medium-power tests on the transmitter line duplexer indicate a leakage power about 83 db below an average operating power level of 60 kw. A temperature rise of 25°C was found at this level in the input hybrid, however, and means to reduce this are being studied.

The normalizing amplifiers necessary to permit proper operation of the monopulse angular tracking circuitry have been completed and are now installed in the receiver room.

II. 220-FOOT ZENITH ANTENNA (Incoherent Ionospheric Backscatter)

In January 1963, routine ionospheric observations were started using the new 220-foot parabola. These observations generally take the form of a continuous sequence of measurements extending over a period of 24 hours and are made at intervals of about 10 days. The electron-density profile in the ionosphere over a height interval of 180 to (at best) 1000 km is measured approximately once an hour using computer integration. Concurrently, the analog integrator is

used to measure the spectra of the signals returned from different heights in the range 180 to 600 km. Despite the fact that the equipment is operated only once every 10 days, it has not been possible to reduce the data as quickly as it has been acquired. At the present time few electron-density profiles have been reduced, and only about half the spectrum measurements fully analyzed. Nevertheless, the measurements obtained thus far are very rewarding. The variation of the electron and ion temperatures (separately), both as a function of height up to 600 km and time, can be obtained. The new results confirm those obtained in the spring of 1962 and show that, for most parts of the day, the electron temperature is greater than the ion temperature by as much as a factor of three. The diurnal variation is complex, the greatest ratios being observed in the forenoon between 8 and 10 a.m. A subsidiary maximum occurs between 4 and 5 p.m. During most of the day, the ratio between the temperatures increases with height. It is not yet clear at what height thermal equilibrium between the electrons and ions is re-established. These findings are of paramount importance in the interpretation of the results of the Canadian (Alouette satellite) topside sounder. Thus, efforts will be made to operate the equipment at times when this satellite passes close to Millstone.

III. HAYSTACK FACILITY

During the present reporting period, the Univac 490 digital computer was received. Some small difficulties were uncovered and the unit is now undergoing acceptance tests. It is expected that checkout of antenna-pointing routines will start shortly.

The Radiation at Stanford transmitter power supply arrived in mid-March. By the end of March, transformers, rectifier stack shells, capacitors with resistive networks, heat exchangers and the DC dummy load were installed.

The antenna bearings, transition and yoke arms have arrived on-site from North American Aviation. At the end of March, the bearing assembly was nearing completion. The numerous measurements necessary to ensure proper bearing leveling and runout clearance have delayed erection.

Specifications for the Haystack radiometer system, which will be used in calibrating the antenna, have been completely drawn up and many of the parts ordered. It appears that many measurements of basic interest in radio astronomy may result as a by-product of the antenna investigation.

ANTENNAS
GROUP 315

I. EL CAMPO ANTENNA

All the equipment necessary to double the size of the antenna has been received on the site, and a subcontractor has been selected to install this equipment under the supervision of Lincoln Laboratory personnel. The installation is expected to continue through the first weeks of May 1963, and will be followed by an intensive adjustment and checkout program resulting in the completion of this modification by the end of the next quarter.

II. PROJECT WEST FORD

The feasibility model of the switched-beam directive antenna system has been completed, and final data are available. Significant improvements are being made in the antenna and switching components used in this feasibility model. Specifically, the right- and left-hand circular polarization diplexing unit has been improved by replacing miniature coaxial cables with an all-waveguide circuit that utilizes the properties of orthogonal dominant modes in a circular waveguide. This results in an increase in the antenna gain from 11 to approximately 12.3 db, maintaining the same effective coverage. The first solid-state switch was constructed in strip transmission line and was a single-pole 4-throw unit instead of a single-pole 32-throw unit. It is planned to use ten single-pole 4-throw switches and one single-pole double-throw switch to make up the desired single-pole 32-throw switch. Extrapolation from the data already obtained indicates that the single-pole 32-throw switch would have an insertion loss of approximately 4.5 db and an isolation of about 20 db. A single-pole single-throw solid-state waveguide switch having an insertion loss of 0.4 db and an isolation of approximately 22 db has been completed. Extrapolating from these data to the 32-throw unit indicates that the insertion loss will be approximately 3 db, and the isolation will be greater than 20 db. Several other one-quarter-height and half-height waveguide components are being developed for use in the remaining interconnections and circuitry.

The improved West Ford tracking feed system consisting of a long horn with a diamond aperture, a circular-polarized transducer, and a dual-polarization exciter has been completed. Experimental results obtained with the antenna radiating linearly polarized signals indicate excellent performance in both the communications and tracking modes. The sum channel, or on-axis beam, has extremely low sidelobes in both principal planes when operating at either 7750 or 8350 Mcps. The sidelobes in the 45° planes are approximately 15 db down, and the main beam is essentially circular in shape; that is, it has equal principal-plane half-power beamwidths. The error-channel radiation patterns are equal to or better than those that can be obtained with a conventional four-horn monopulse system. The maximum gain of both difference patterns is approximately 3 db below the maximum of the sum-channel beam.

The circular-polarization transducers were tested separately and produced a circularly polarized wave whose axial ratio varied from 0.3 db at the center of the band to approximately 2 db at

the edges of the band. When four of these circular-polarization transducers were inserted into the excitation network of the West Ford diamond horn, the radiation patterns proved to be unsatisfactory. The axial ratio increased to 3 db for the on-axis beam and to greater than 10 db for the error patterns. These results were improved somewhat by changing the length of the transitions between the four-port monopulse exciter and the input to the diamond horn; however, the performance was still considered unsatisfactory. The circular-polarization transducers were removed from the excitation section of the horn, and a metal-plate polarizer was positioned across its aperture. The measured performance has improved considerably; however, there is still room for improvement and not all the necessary data have been taken. The metal plates of the circular-polarization transducer tend to produce a field distribution over the aperture of the horn which is similar to that obtained with a conventional pyramidal horn. The excellent performance obtained with the linearly polarized diamond horn justifies an investigation of the possibility of using a dielectric-plate polarizer over the aperture of the horn, or of using a circular-polarizing reflector over the hyperboloid Cassegrainian reflector in place of the metal-plate unit. The latter method would guarantee excellent results because of the proven performance of the diamond horn and the simplicity in design of a circular-polarizing hyperboloid reflector. Present plans include using the metal-plate circular-polarization transducer with an interim feedhorn and installing the best of the proposed designs during the next quarter.

In order to provide the required isolation between the transmitter and the receiver, a new type of filter has been developed which produces more than 50 db isolation over a 20-Mcps stop band and has less than 0.1 db insertion loss over the pass band. The unit has been designed to accommodate the present West Ford frequencies of 8350 and 7750 Mcps. This unit, used in conjunction with the circular-polarization filters described in the last quarterly progress report, is functioning satisfactorily at one of the West Ford sites.

III. RADIO ASTRONOMY BOX FOR HAYSTACK HILL ANTENNA

The feed described in a journal article in July 1954,* and recently suggested by John Ruze, was constructed and is presently being tested. Two feeds were constructed, one operating at 7750 Mcps for use with a 16-inch paraboloid and the other operating at 15,375 Mcps for use with an 8-inch paraboloid. Radiation patterns have been measured at both frequencies and found satisfactory. The objective of obtaining equal E- and H-plane beamwidths within a 13.4° included angle has been reached, and the near-in sidelobe levels are approximately −20 db. Gain and impedance measurements have not yet been made; however, it is planned that these data will soon be taken. The radiation patterns will be integrated to determine the fraction of power intercepted by the subreflector. This factor, together with the calculated "illumination" efficiency of the secondary aperture, will allow prediction of the antenna efficiency and gain with considerable accuracy.

IV. MILLSTONE HILL RADAR

The radiation patterns of the 12-horn monopulse feed system have been measured with unit-radiating linearly polarized signals. The agreement between measured and expected results

* A. Chlavin, "A New Antenna Feed Having Equal E- and H-Plane Patterns," Trans. IRE, PGAP AP-2, No. 3, 113 (1954).

has been excellent; however, the measured gain is not the same for both vertical and horizontal polarization. Subsequent tests have shown that this is due to the mutual interaction between the center four feedhorns and the outside horns. Further tests have shown that the coupled signals are transmitted to the short-circuited terminals of the outer horns; by adjusting the position of these short circuits, the antenna gain can be made identical for both polarizations. A practical application of this arrangement would require a number of adjustable short circuits placed at these terminals and positioned to produce the desired results. Unfortunately, the optimum position would vary as a function of frequency. Alternatively, these terminals could be terminated in a matched load, thereby eliminating the frequency sensitiveness of this effect and perhaps reducing the maximum gain obtainable by ~0.2 db. Because the gain of the antenna system is proportional to the gain of the feed system, it is important to attempt to increase the latter to its maximum value. However, the present system will not be modified at this time; rather, at some time in the future a modification kit will be installed for the purpose of achieving the desired results.

Extensive radiation pattern measurements and gain measurements were conducted with the interim feedhorn illuminating the 84-foot-diameter paraboloid. Unfortunately, the interim feedhorn was not properly designed, and the antenna system had a measured gain ~2 db below an optimum value. After installing a correcting lens, the antenna efficiency was increased to 40 percent. This was increased to ~50 percent by removing a set of buttons that were placed in the throat of the feedhorn to increase the isolation between the dual-polarization input terminals.

V. PROJECT 461

The four-horn monopulse-tracking feed system which will be used to illuminate the 30-foot paraboloid is nearly completed. The variable-polarization transducers have been completed and are being assembled with the feedhorns. Final evaluation of the comparator circuitry has been completed and its performance is satisfactory. This feed system should be ready for installation in the antenna system by mid-April 1963.